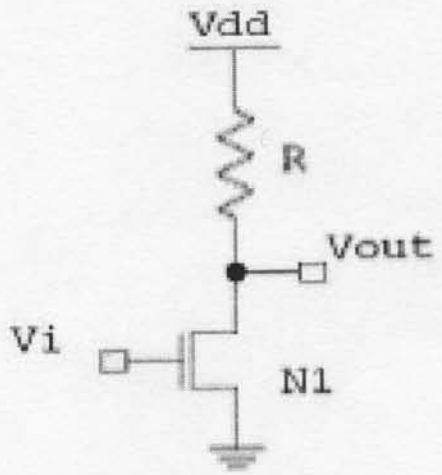
Esercizio 1



Parametri Tecnologici
V_{DD} =3.3 V
K'_n =100 μA/V²
K'_p =50 μA/V²
L_{min}=0.35μm
$V_{TN}=\|V_{TP}\|$=0.7 V
S = 5
R = 30 KΩ
γ = 0
λ = 0

1. Tracciare qualitativamente la caratteristica statica del gate, dividendola in regioni corrispondenti alle regioni di funzionamento dei transistori
2. Individuare i punti in cui si verifica una cambiamento della regione di funzionamento
3. Calcolare il valore della V_{OUT} per $V_{IN} = V_{DD}$ e per $V_{IN}=0$
4. Calcolare il valore della soglia logica del gate
5. Calcolare la corrente che scorre sul gate nei punti individuati
6. Determinare lo swing logico del gate

1)

Se $0<V_i < V_{Tm}$ ⟶ N1 OFF ⟶ $I_{DS_{N_1}} = 0$ $\boxed{V_{OUT} = V_{DD}}$

Se $V_i > V_{Tm}$ ⟶ N1 ON $V_{DS_{V_i = V_{Tm}}} = V_{DD} > V_{GS} - V_{Tm}$

inizialmente N1 saturo

N1 saturo ⟶ $I_{DS_{N_1}} = \frac{\beta_m}{2}\left(V_i - V_{Tm}\right)^2$

$$\boxed{V_{OUT} = V_{DD} - R\,\frac{\beta_m}{2}\left(V_i - V_{Tm}\right)^2}$$

N1 esce di saturazione quando $V_{OUT} = V_i - V_{Tm}$

$$V_i - V_{Tm} = V_{DD} - R\,\frac{\beta_m}{2}\left(V_i - V_{Tm}\right)^2$$

$$\frac{2}{R\beta_m}(V_i - V_{Tm}) = \frac{2V_{DD}}{R\beta_m} - (V_i - V_{Tm})^2$$

$$(V_i - V_{Tm})^2 + \frac{2}{R\beta_m}(V_i - V_{Tm}) - \frac{2V_{DD}}{R\beta_m} = 0$$

$$V_i - V_{Tm} = -\frac{1}{R\beta_m} + \sqrt{\left(\frac{1}{R\beta_m}\right)^2 + \frac{2V_{DD}}{R\beta_m}}$$

$$\beta_m = \beta'_m \cdot S = 100 \cdot 10^{-6} \cdot 5 = 500 \frac{\mu A}{V^2}$$

$$R\beta_m = 500 \cdot 10^{-6} \cdot 30 \cdot 10^3 = 15 \ V^{-1}$$

$$V_i - 0{,}7 = -\frac{1}{15} + \sqrt{\frac{1}{225} + \frac{6{,}6}{15}} = -\frac{1}{15} + \sqrt{\frac{1+99}{225}} =$$

$$= -\frac{1}{15} + \frac{10}{15} = \frac{9}{15} = \frac{3}{5} = 0{,}6$$

$$\boxed{V_i^* = 0{,}7 + 0{,}6 = 1{,}3V} \qquad V_{OUT}{}_{V_i = V_i^*} = 3{,}3 - \frac{15}{2}(0{,}6)^2 = 0{,}6V$$

$V_i > V_i^* \longrightarrow$ N1 ON in regiome TRIODO

$$I_{DS_{N_1}} = \frac{\beta_m}{2}\left[2(V_i - V_{Tm}) \cdot V_{OUT} - V_{OUT}^2\right]$$

$$V_{OUT} = V_{DD} - R\, I_{DS_{N_1}} = V_{DD} - R\beta_m (V_i - V_{Tm}) V_{OUT} + \frac{R\beta_m}{2} V_{OUT}^2$$

$$\frac{R\beta_m}{2} V_{OUT}^2 - R\beta_m (V_i - V_{Tm}) V_{OUT} + V_{DD} - V_{OUT} = 0$$

$$V_{OUT}^2 - \frac{2}{R\beta_m}\left[R\beta_m (V_i - V_{Tm}) + 1\right] V_{OUT} + \frac{2V_{DD}}{R\beta_m} = 0$$

Se $V_i = V_{DD}$

$$V_{OUT}^2 - \frac{2}{15}\left[15 \cdot 2{,}6 + 1\right] V_{OUT} + \frac{6{,}6}{15} = 0$$

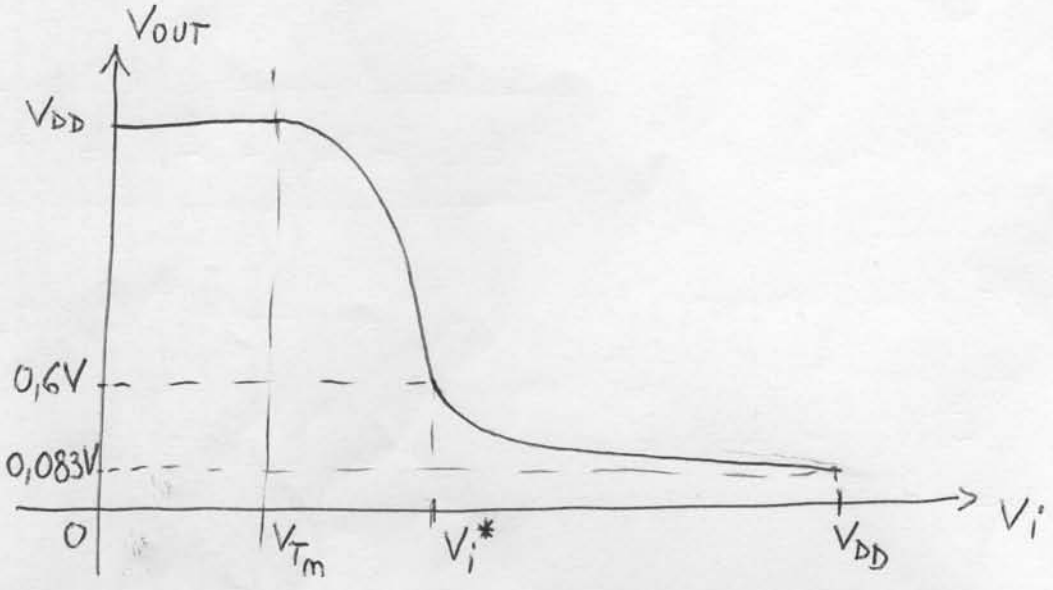
$$V_{OUT}^2 - \frac{2}{\cancel{15}_3}\cdot\cancel{40}^{8}\, V_{OUT} + \frac{6{,}6}{15} = 0$$

$$V_{OUT}^2 - 2 \cdot \frac{8}{3} V_{OUT} + \frac{6{,}6}{15} = 0$$

$$V_{OUT} = \frac{8}{3} \pm \sqrt{\frac{64}{9} - \frac{6{,}6}{15}} =$$

$$= \frac{8}{3} \pm \sqrt{\frac{320 - 19{,}8}{45}} = 2{,}666 \pm \sqrt{6{,}671} =$$

$$= 2{,}666 \pm 2{,}583 \begin{cases} 5{,}249 \quad \text{NO!} \\ 83\ mV \end{cases}$$



2) $V_i = 0 \longrightarrow V_{OUT} = V_{DD} = 3{,}3\,V$

$V_i = V_{DD} \longrightarrow V_{OUT} = 83\ mV$

3) $V_i = V_{LT} \longrightarrow V_i = V_{OUT} \longrightarrow$ N1 saturo

$$V_{LT} = V_{DD} - \frac{R\beta_m}{2}\left(V_{LT} - V_{Tm}\right)^2$$

$$V_{LT} = 3,3 - \frac{15}{2}\left(V_{LT} - 0,7\right)^2 = 3,3 - \frac{15}{2}\left(V_{LT}^2 - 1,4\,V_{LT} + 0,49\right)$$

$$\underbrace{\frac{2}{15}}_{0,133} V_{LT} = 0,44 - V_{LT}^2 + 1,4\,V_{LT} - 0,49$$

$$V_{LT}^2 - 1,267\,V_{LT} + 0,05 = 0$$

$$V_{LT} = 0,6335 \pm \sqrt{0,4013 - 0,05} = 0,6335 \pm 0,5927$$

$V_{LT} =$ 40,8 mV IMPOSS

$V_{LT} =$ 1,226 V

$$\boxed{V_{LT} = 1,226\,V}$$

4) $V_i = 0 \longrightarrow V_{OUT} = V_{DD} \longrightarrow I_{DD} = 0$

$$V_i = V_{DD} \longrightarrow V_{OUT} = 83\,mV \longrightarrow I_{DD} = \frac{V_{DD} - V_{OUT}}{R} = \frac{3,217}{30 \cdot 10^3}$$

$$= 107,23\,\mu A$$

$$V_i = V_{LT} \longrightarrow V_{OUT} = V_{LT} \longrightarrow I_{DD} = \frac{V_{DD} - V_{LT}}{R} = \frac{2,074}{30 \cdot 10^3} = 69,13\,\mu A$$

5)

$V_{OH} = V_{DD} = 3,3V$

$V_{OH} - V_{OL} = 3,217\,V$

$V_{OL} = 83\,mV$